The Fund for Animals
we speak for those who can't

May 16, 2001

Donna Wieting, Chief
Marine Mammal Conservation Division
National Marine Fisheries Service
1315 East-West Highway
Silver Spring, Md. 20910

Dear Ms. Wieting,

Our California office of The Fund for Animals wrote your office previously, with reference to the Navy's proposed LFA sonar deployment.

Please enter for consideration the attached paper by physicist Dr. Norman T. Seaton. His commentary, prepared initially in reference to ATOC, contains material that is applicable now to the subject at hand.

It is hoped that the N.M.F.S. and the Navy can be convinced of the folly of supposing that LFA sonar testing can do any other than wreak havoc and destruction to marine life.

Sincerely

Virginia Handley

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Commentary on

Acoustical Thermometry of the Ocean Climate
by
Norman T. Seaton, PhD.
(Science adviser to The Fund for Animals)

Introduction:

The purported purpose of the proposed experiment on Acoustical Thermometry of the Ocean Climate (ATOC) is to evaluate the possibility of using measurements of the velocity of sound over great ocean distances and changes in this velocity to determine global warming, or the lack of it. The assumption of the experiment is that the velocity of sound can be measured with sufficient accuracy to make such a determination within a reasonable time, say 10 years. That brings up two problems: the immediate problem of obtaining accurate baseline data on sound velocity to which later sound velocity measurements can be compared. In the Pacific Ocean at least such data could be severely compromised by the presence or absence of the highly unpredictable El Nino effect. A second and more important problem however relates to the assumption itself. A significant portion of this commentary is devoted to demonstrating the invalidity of this assumption.

As a physicist, if I were asked how I would determine the presence or absence of global warming, I would say look to rainfall measurements throughout the world. It is well known from high school physics and chemistry that the vapor pressure of water increases from less than 5 mm of Hg at 0°C to 760 mm at 100°C. The condensation of such vapors leads to rainfall on both land and sea, so that rainfall becomes a very sensitive indicator of water vapor pressure and ocean surface temperature. Such a conclusion is of course hardly news to anyone who has ever lived in the tropics or near a rain forest. The use of rainfall data has the great advantage that accurate data has already been collected for many decades in the developed parts of the world at least. Thus accurate baseline data is already available there for reference purposes. Furthermore the physical apparatus for making future measurements is already in place and will be used for local purposes, even if not summed up to indicate global warming. In the undeveloped parts of the world a measure of rainfall could, wihout a lot of difficulty, be obtained by observing the run-off flow rate at the mouth of selected rivers. (Data from flow rate measurements could easily be sent via radio to a central processing station). While such rainfall measurements would give only an indication of rainfall on the 30 % of the earth's surface covered by land, they would nevertheless clearly be indicative of the presence or absence global warming. And of course the gathering and summing up such data poses no hazard to man, whales, fish, or any other part of the ocean environment.

ATOC, Physics, and the Deep Sound Channel:

The premise of ATOC is that sound velocity varies with the temperature of the sea water, and indeed it does, changing by about 1 part in 500 at sea level for every degree centigrade change. The velocity of sound also increases with salinity, and in an almost linear fashion, with depth. The empirical formula often used is:

$$c=1410 + 4.21t - .037t^2 + 1.14S + .018d$$

where c is the velocity of sound in meters/second, t is the temperature in degrees C, S is the salinity in parts per thousand (typ. 32), and d is the depth in meters. (At sea level the velocity of sound is about 1500 m/s or 3,355 mph). From the above formula it is evident that the dominant factors determining the velocity of sound are temperature and depth. (Changes in salinity essentially play only a minor part except near the mouth of rivers). Changes in sound velocity with temperature and depth determine how a sound beam is refracted or bent. It is particularly instructive to look at the variation of temperature with depth, the thermocline, in the great oceans and to look at a typical sound velocity profile resulting from the thermocline curve and the increase in velocity that accompanies increasing depth. These curves are shown in Figs. 1 & 2. You will note that as a function of depth the ocean temperature first exhibits an essentially isothermal region near the surface followed by a rather rapid decline to about 4°C after which it slowly increases as the ocean floor is approached.

The accompanying depth velocity profile, Fig, 2, has for convenience of discussion been broken up into three regions approximated by the straight lines shown. Regions I & III have essentially the same slope as determined by the depth factor because temperatures there are nearly constant; in region II however the slope is reversed because of the overwhelming effect of the temperature decrease in that region. A sound wave launched horizontally in region III will slowly be deflected upward because at lower depths the speed of sound is higher so that the separation between wavefronts becomes larger. This depicted in drawing IIIc. This situation also applies to region I as depicted in drawing Ia. In region II a horizontally directed beam will be refracted downward as shown in drawing IIb. Such a wave, starting for example at point P in Fig. 3, will cross the division line between regions II & III and then start to curve upward and the cycle is repeated again and again with very little attenuation other than in principle the 1/distance factor. In Fig. 3 we have shown the path of sound waves initiated on the surface at S and in the deep sound channel at D, i.e. centered on the division line between regions II & III where the sound velocity has its minimum value. It is of interest to note that over a distance of 3,000 km (1,864 mi.) the time taken for the longer paths can be as much as 10 seconds less than that for a direct path (a garbled signal rumbles in and ends abruptly). In Fig. 4 we have shown the attenuation as a function of frequency for both fresh and salt water, the deviation of the latter being attributed to the relaxation effects of the dissolved magnesium sulphate in sea water. The efficiency with which sound power can be transmitted even in sea water is truly remarkable and all the more so at low frequencies. ATOC's desire to use low frequency emission in the middle of deep sound channel is therefore understandable if one disregards the needs of deep sea animals, essentially blind except for their remarkable abilities with underwater sound.

In conclusion, it should be clear from the foregoing discussion that changes in the deep sound channel temperature can only occur over very long periods of geologic time.

There is not even the remotest possibility of using any measurement of sound velocity in the deep sound channel to indicate global warming, and to imply otherwise with a name, such as Acoustic Thermometry of the Ocean Climate, is an affront to responsible science and the public pocketbook.

Sound Levels and Biological Effects:

Proponents of ATOC like to point out that the sea is a very noisy place and that the sound levels of 195 dB they plan to use are the same as that generated by a supertanker, but that argument is disingenuous on two scores. Firstly the supertanker is not **in** the deep sound channel, and secondly, most of the frequency spectrum of the racket generated by the supertanker will not be in the range of frequencies used by most marine mammals.

As can be inferred from Fig. 3, most sounds generated on the surface get launched at an angle so shallow that they get refracted back up to the surface to be scattered by waves, or the launching angle is so steep that they pass right through the deep sound channel and get scattered from the ocean floor. Sounds on the surface must be launched within a very narrow range of angles if they are to get into the deep sound channel **and stay in it.** On the other hand the power of the ATOC signal will undoubtedly be phased by their vertical line array so that **most of it stays in the deep sound channel.** While the ATOC sound may be greatly attenuated by the time it gets to the receivers, there will be vast volumes of the ocean where it will not be all that weak in comparison to whale vocalizations that another whale may be trying to hear.

The other problem with the ATOC emission relates the frequencies which they propose to use and the problem of masking. Masking raises the threshold of hearing for a particular sound when another unwanted one of a frequency close to that of the particular sound of interest is added into the mix. The masking effect is always much worse when the masking sound has the same or a somewhat lower frequency than the ones of interest. The effect is much less when the unwanted frequency is an octave or more higher than those of interest. The ATOC sound could thus be particularly stressful and perhaps even fatal to the existence of the larger deep diving whales that have low frequency vocalizations and use the deep sound channel for communication.

Final Conclusion:

I believe the permit to conduct marine mammal research should be denied to ATOC. It is particularly odious that ATOC proposes to do this research in a marine sanctuary like that in Monterey Bay and in a known whale breeding ground like that off Kauai. Enough public monies have already been wasted on this project, and the balance of whatever funding remains should be used for some really useful purpose.

Appendix

The theory of heat diffusion in materials has long been a subject of interest to mathematicians and physicists alike starting with Fourier, Laplace, Lord Kelvin and others. The basic differential equation for heat diffusion throughout a body can be expressed by the equation:

$$\frac{\partial T}{\partial t} = \alpha \, \Delta T$$

Where T is the temperature at any point, t=time, and Δ=the Laplacian operator. The diffusivity constant $\alpha = k/c\rho$ where k=heat conductivity, c=specific heat, ρ=density is a function of the particular material considered (and for water α is especially small).

For the rather simple example we wish to consider the above partial differential equation reduces to an ordinary differential equation:

$$\frac{dT}{dt} = \alpha \frac{d^2 T}{dz^2}$$ where again t=time, z=distance down

Many different kinds of solutions to this simple one dimensional heat flow equation, corresponding to different boundary conditions, are worked out in the text "The Mathematical Theory of Heat Conduction" by Ingersoll and Zobel. Sections 7.14 & 7.15 are pertinent to the type of situation we wish to consider, i.e. a large expanse of water where at least below a given depth there is no convective mixing up* of whatever temperature stratification exists there. Consider a column of water that is thermally isolated so no heat comes into the column through its sides but only in the z direction from the top down. We will further assume that we can raise and keep raised the top 250 meters by 10°C, and we ask the question: in 10 years at what depth will the temperature rise by 1/10,000th °C because the temperature of the top 250 meters has been raised by this 10°C. The solution to the differential equation is that given by 7.14(b)

$$T = T_s[1-\Phi(nz)] \quad \text{where} \quad \Phi = \frac{2}{\sqrt{\pi}}\int_0^{nz} e^{-\beta^2} d\beta \quad \text{is the probability integral}$$

Here $n = 1/2\sqrt{\alpha t}$ and T_s is the amount the temperature was raised down to the 250 meter level and z is the distance down from that level. Putting in $T=10^{-4}$°C and $T_s=10$°C we have $[1-\Phi(nz)]=10^{-5}$, corresponding nz=3.12 (see probability integral tables). Since $\alpha=1.31\times10^{-3}$ for water, and taking $t=3.1536 \times 10^{8}$ seconds (10 yrs), we find $n=7.78 \times 10^{-4}$ cm^{-1}, whence z=4010.7 cms or 40.1 meters, and the distance from the top will be 290.1 meters. To find the time for the same rise to occur at 900 meters, we will have t=10 yrs x $(650/40.1)^2$=2627 years from the law of times (7.15). **If we were to raise just the very top surface of the ocean by 10°C, the time required for that temperature rise to diffuse down to 900 meters and give a 1/10,000th °C increase would be 5,000 years!****

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* The Heard Island experiment was done at a depth of 175 meters, where according to Fig. 4.4 of Tucker & Gazey, diurnal variations can still show up (perhaps explaining whatever results were obtained there).

** An intriguing question is: can the time of the last ice age be predicted from the upper section I of the thermocline curve (Fig. 1) in view of its close resemblance to the probability integral curve (taking 4°C as a baseline).